

Study of cluster shapes in the MIMOSA-5 pixel detector

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Abstract

Beamstrahlung will constitute an important source of background in a pixel vertex detector at the future International Linear Collider. Electron and positron tracks of this origin impact the pixel planes at angles generally larger than those of secondary hadrons and the corresponding clusters are elongated. We report studies of cluster characteristics using test beam electron tracks incident at various angles at a Mimosas-5 pixel matrix.

1 Introduction

Precise spatial reconstruction of tracks and secondary vertices is imperative for flavour identification in experiments at the future International Linear Collider, where electron and positron beams will be colliding at the centre-of-mass energies up to 1 TeV [1]. This can be achieved by means of a multi-layer pixel vertex detector, enveloping the beam pipe near the interaction point. Such a detector may be built of rectangular pixel matrices, arranged quasi cylindrically (with possible end caps) [2]. Charged final state particles from the e^+e^- interactions will traverse the detector layers and each particle will deposit charge in a group of pixels, forming a cluster. The vertex detector will be also exposed to an important source of background - beamstrahlung. This is an electromagnetic process in which a bremsstrahlung photon creates an electron - positron pair in the interaction region of the colliding beams. Subsequently these pairs will enter the vertex detector among other products of the interaction and create numerous additional clusters.

The orientation of a track w.r.t. a given pixel matrix plane may be described in terms of two angles as shown in fig. 1: (i) the polar angle θ which is the angle between the track and the normal to the matrix plane and (ii) the azimuthal angle ϕ which is the angle between the direction of the track projected to the matrix plane and one of the matrix axes.

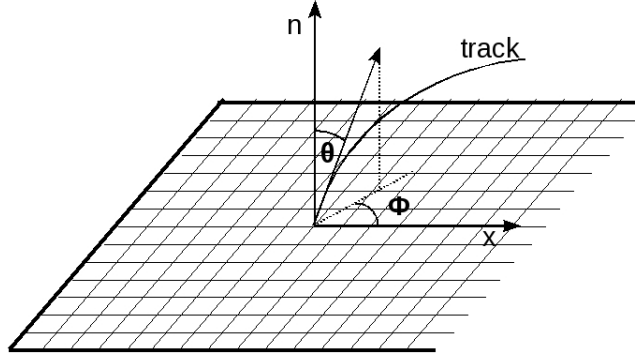


Figure 1: Definition of the polar and azimuthal angles, θ and ϕ , in the MIMOSA-5 coordinate system with the X axis parallel to the MIMOSA-5 edge; n - normal to the pixel plane.

Simulations have shown [3]: (i) the presence of the beamstrahlung background deteriorates flavour identification; (ii) the angles θ and ϕ of beamstrahlung tracks differ from those of the final state particles from e^+e^- interactions. Meanwhile one expects that the cluster shape depends primarily on the angle of incidence, θ , of a given track. Since the beamstrahlung tracks traverse pixel matrices predominantly at large angles θ , one may expect that the corresponding clusters will be elongated for sufficiently large values of this angle. The aim of the present paper is to study this effect, which might appear helpful for identification of beamstrahlung clusters on the basis of their shape and orientation on the pixel plane.

Monolithic Active Pixel Sensor, MAPS, is one of the vertex detector technology concepts presently under consideration. Studies show that the MAPS matrices may have spatial resolution of the order a few μm , almost 100% detection efficiency, possess good resistance to radiation and can be thinned down to about $50 \mu\text{m}$ [4]. We have used the MIMOSA-5¹ MAPS prototype for our studies. The device was fabricated in the AMS $0.6 \mu\text{m}$ CMOS technology. The epitaxial layer, which constitutes the sensitive volume of the detector, was $14 \mu\text{m}$ thick. We have used a module of 510×512 pixels ($8.7 \times 8.7 \text{ mm}^2$). Pixel dimensions were $17 \times 17 \mu\text{m}^2$ and those of the charge collecting diodes $4.9 \times 4.9 \mu\text{m}^2$. The data acquisition system is described elsewhere [5].

2 Experimental setup

The experimental setup included the MIMOSA-5 matrix, the beam telescope and trigger counters, as shown in fig. 2. The MIMOSA-5 matrix was mounted on an adjustable mechan-

¹Minimum Ionizing particle MOS Active pixel sensor

ical support, enabling rotations around the X and Y axes and was contained in a polystyrene box for thermal insulation. The matrix was oriented manually to the desired angles before each data taking run using the angular scale of an accuracy of approximately $\pm 1^\circ$. Precise determination of the angles was performed offline in the alignment procedure (see below).

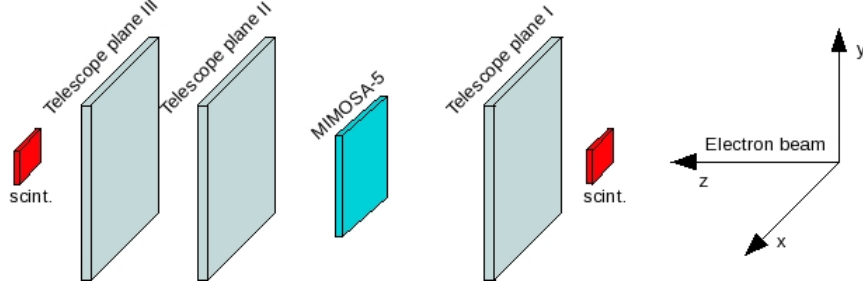


Figure 2: Schematic view of the experimental setup (see text).

The beam telescope consisted of a set of three microstrip units, each unit built of two planes of perpendicularly oriented microstrips. One unit was placed in front and two other behind the MIMOSA-5. Each telescope plane had an area of $32 \times 32 \text{ mm}^2$ and the overall detection efficiency higher than 99% [6]. The beam telescope enabled reconstruction of the beam track position at the MIMOSA-5 matrix with accuracy better than $10 \mu\text{m}$ at the offline analysis stage. Three small plastic scintillator detectors were placed on the beam (two in front and one behind the beam telescope), serving as trigger counters.

The MIMOSA-5 matrix was exposed to the DESY electron beam of energies from 1 to 6 GeV. The measurements were done for various orientations of the matrix w.r.t. the beam. Approximately 5k triggers were collected for each run.

3 Measurement of cluster shapes

The first step in the data analysis was the evaluation of the pedestals and noise levels for each pixel. Clusters of pixels were reconstructed as follows. Pixels with locally maximal charge (the seed) were identified as the highest among 8 adjacent pixels. It was required that the signal to noise ratio, S/N , for the seed was greater than 5. In order to remove fake clusters (formed around malfunctioning pixels) an additional cut was applied. For this purpose the following variables were defined: (i) $\mathcal{S}_8 = \sum_{i=1}^8 q_i$ - the total charge collected in 8 pixels adjacent to the seed and (ii) $\mathcal{N}_8 = \sqrt{\sum_{i=1}^8 N_i^2}$ - average noise of these pixels, where q_i and n_i are the charge and the noise of the i -th pixel, respectively. If the condition $\mathcal{S}_8/\mathcal{N}_8 > 0.5$ was fulfilled, the group of 9×9 pixels around the seed was taken under consideration. The 81 pixels were sorted in the descending order with respect to the charge. It was then accepted that a cluster is formed of the first N_c consecutive pixels, counting from the seed (highest charge), which carried 90% of the total charge of the 9×9 group. Average values of the number of pixels forming a cluster, N_c , ranged from about 6 to 14, for almost perpendicular ($\theta \approx 4^\circ$) and very inclined tracks ($\theta \approx 78^\circ$), respectively. It was

assumed that the charge-weighted centre of gravity of a cluster coincided with the track position at the matrix surface. Cluster positions and track positions extrapolated from the telescope constituted partial input for the offline alignment. This procedure was based on χ^2 minimisation involving parameters describing the position and angular orientation of the matrix w.r.t. the telescope reference frame. The procedure allowed computing precise values of the θ and ϕ angles for a given, manually preset, orientation of the pixel matrix. The accuracy of the angle determination using alignment was better than 0.1° .

Particles passing through the detector at low incident angles leave statistically round clusters. Since in a MAPS detector the charge transport is by diffusion, it is expected that clusters arising from sufficiently inclined tracks should be elongated in the track direction projected to the pixel plane while unaltered in the perpendicular direction. We have measured the magnitude of elongation as a function of the incident angle θ and determined orientation of elongated clusters on the matrix plane in terms of the angle ϕ .

Shapes of individual clusters are subject to statistical fluctuations due to fluctuations of charge deposited in pixels. For the purpose of visualisation we averaged clusters over approx. 1.5 k events taken at the same θ and ϕ settings. In fig. 3 we show two distinct cases: averaged clusters arising from (a) electron tracks incident at $\theta \approx 4^\circ$ and (b) tracks incident at $\theta \approx 78^\circ$; the elongation of the averaged cluster is clearly visible in the latter case.

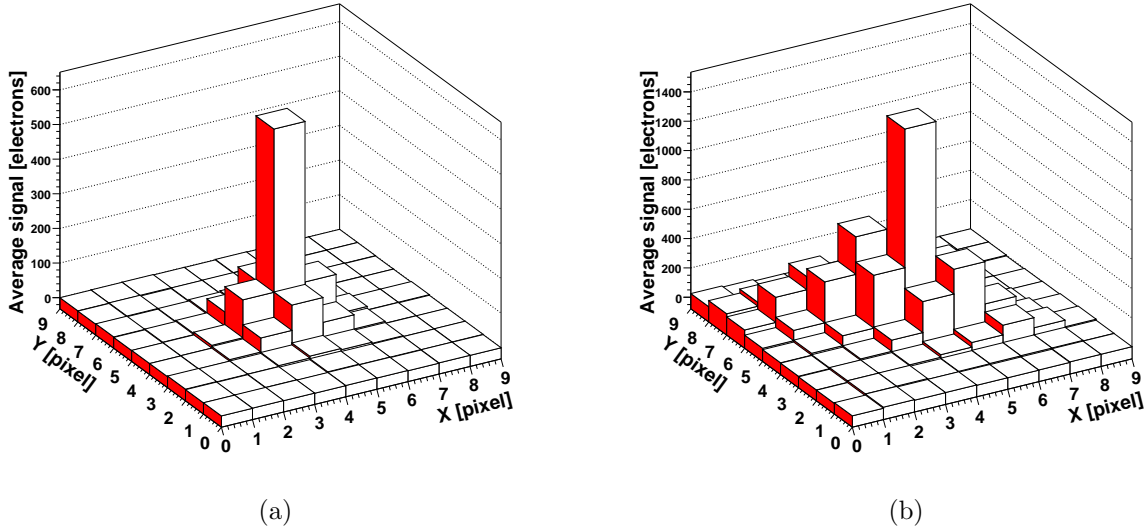


Figure 3: Spatial distribution of charge in an averaged cluster for two different incident angles: (a) $\theta = 4.3^\circ$ and $\phi = -44.0^\circ$, (b) $\theta = 78.1^\circ$ and $\phi = -37.8^\circ$.

The shape of a single cluster, its longitudinal and transverse dimensions, may be obtained from the following procedure. The charge distribution matrix in a given cluster was defined as:

$$\begin{pmatrix} \sum_{i=1}^{N_c} \frac{q_i}{Q} (x_i - \bar{x})^2 & \sum_{i=1}^{N_c} \frac{q_i}{Q} (x_i - \bar{x}) (y_i - \bar{y}) \\ \sum_{i=1}^{N_c} \frac{q_i}{Q} (x_i - \bar{x}) (y_i - \bar{y}) & \sum_{i=1}^{N_c} \frac{q_i}{Q} (y_i - \bar{y})^2 \end{pmatrix}, \quad (1)$$

where Q is the cluster charge, q_i is a charge of the i -th pixel, x_i , y_i are its positions in the MIMOSA-5 coordinates sytem and the \bar{x} and \bar{y} are the coordinates of the considered cluster in the latter coordinates system. The \bar{x} and \bar{y} were assumed to be the charge-weighted centre of gravity of the cluster:

$$\bar{x} = \sum_{i=1}^{N_c} \frac{q_i}{Q} x_i, \quad \bar{y} = \sum_{i=1}^{N_c} \frac{q_i}{Q} y_i. \quad (2)$$

Diagonalisation of the matrix (1) allowed to determine the eigenvectors, \vec{v}_L and \vec{v}_T , which coincide with the longitudinal and transverse axes of the cluster, respectively, provided the cluster is sufficiently elongated. The corresponding eigenvalues, $\sqrt{\lambda_L}$ and $\sqrt{\lambda_T}$, are proportional to the cluster longitudinal and transverse dimensions.

Given the eigenvectors \vec{v}_L and \vec{v}_T , one may evaluate the azimuthal angle of the cluster w.r.t. the axis of the pixel matrix, ϕ_c , for each individual cluster. The distribution of this angle for a selected data sample of 1 k clusters, taken with the beam setting of $\phi = -37.8^\circ$ and $\theta = 78.1^\circ$, is presented in fig. 4(a).

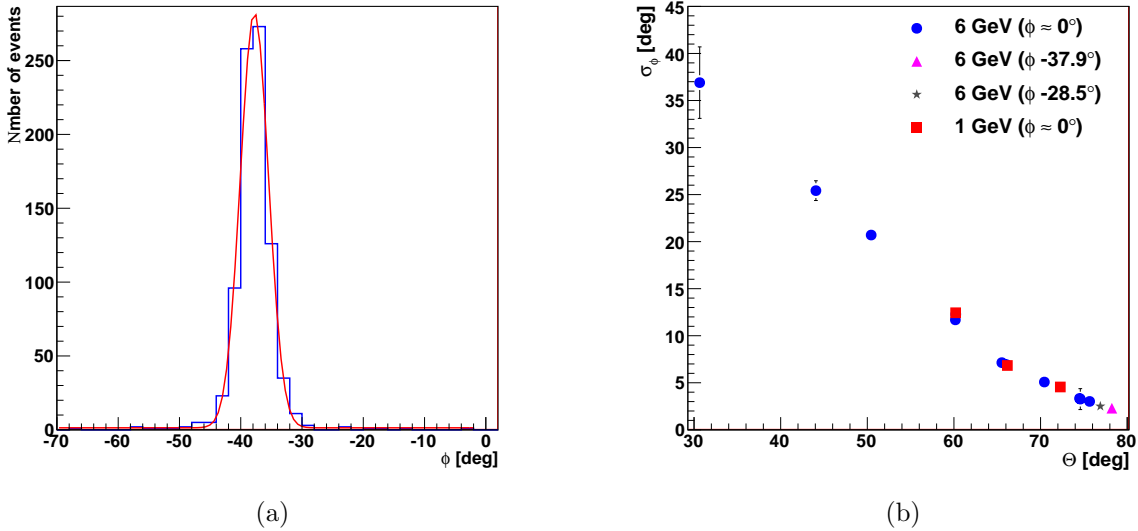


Figure 4: (a) Distribution of the reconstructed ϕ angle, (b) dispersion of the ϕ distribution as a function of the incident angle θ .

The peak position of the distribution in that sample is $\phi_c = -37.9^\circ \pm 0.1^\circ$, in excellent agreement with the actual value quoted above as obtained from alignment. The dispersion of this distribution, σ_{ϕ_c} , obtained from fitting the Gaussian, is $2.4^\circ \pm 0.1^\circ$.

The accuracy of determining the axes of a cluster diminishes as the track becomes steeper and clusters less elongated, which is reflected in increasing dispersion of the ϕ_c distribution. Measurements of the dispersion σ_{ϕ_c} for several values of θ are shown in fig. 4(b), performed using 1 and 6 GeV electron beams and for various ϕ values.

The ratio $\sqrt{\lambda_L/\lambda_T}$ is a measure of cluster elongation. Measured dependence of this quantity on the incident angle θ is shown in fig. 5. Thus we conclude that the cluster elongation

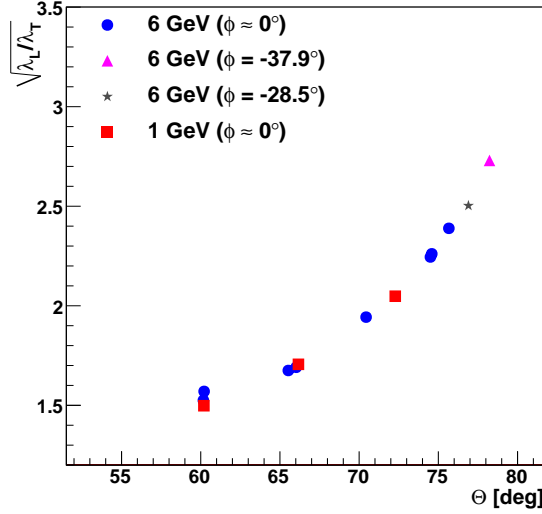


Figure 5: Measured ratio of the longitudinal and transverse dimensions of a cluster as a function of the θ angle.

depends strongly on θ (while there is little or no dependence on beam energy in the studied range). We estimate that this observation is valid for $\theta > 60^\circ$ since for tracks incident at lower angles the elongation of clusters cannot be reliably determined. This can be explained by the fact that in these clusters approximately the same numbers of pixels are involved in charge collection.

4 Conclusions

We have studied cluster shapes using the MIMOSA-5 MAPS detector exposed to 1 and 6 GeV electron beams. Cluster elongation was measured for various orientations of the pixel matrix w.r.t. the beam axis (angles θ and ϕ). The results may be summarised as follows: (i) precision of reconstruction of the azimuthal angle ϕ increases with increasing incident angle θ ; (ii) clusters are elongated for $\theta > 60^\circ$ and the effect grows rapidly with increasing θ , independent of the angle ϕ ; (iii) no energy dependence of the above effects is observed.

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